NASA-CR-200082

Semi ANNUAL REPORT
NASA CONTRACT NAS5-31368
FOR MODIS TEAM MEMBER STEVEN W. RUNNING
ASSOC. TEAM MEMBER RAMAKRISHNA R. NEMANI
SOFTWARE ENGINEER JOSEPH GLASSY
January 15, 1996

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PRE-LAUNCH TASKS PROPOSED IN CONTRACT OF DECEMBER 1991

We propose, during the pre-EOS phase to: (1) develop, with other MODIS Team Members, a means of discriminating different major biome types with NDVI and other AVHRR-based data. (2) develop a simple ecosystem process model for each of these biomes, BIOME-BGC based on the logic of the current FOREST-BGC; (3) relate the seasonal trend of weekly composite NDVI to vegetation phenology and temperature limits to develop a satellite defined growing season for vegetation; and (4) define physiologically based energy to mass conversion factors for carbon and water for each biome.

Our final core at-launch product will be simplified, completely satellite driven biome specific models for ET and PSN based on this modified ΣNDVI logic. These algorithms will be in MODISDIS before launch. We will build these biome specific satellite driven algorithms using a family of simple ecosystem process models as calibration models, collectively called BIOME-BGC, and establish coordination with an existing network of ecological study sites in order to test and validate these products. Field datasets will then be available for both BIOME-BGC development and testing, use for algorithm developments of other MODIS Team Members, and ultimately be our first test point for MODIS land vegetation products upon launch. We will use field sites from the National Science Foundation Long-Term Ecological Research network, and develop Glacier National Park as a major site for intensive validation.

OBJECTIVES:

We have defined the following near-term objectives for our MODIS contract based on the long term objectives stated above.

- Organization of an EOS ground monitoring network with collaborating U.S. and international science agencies.
- Develop advanced logic for landcover classification using carbon cycle simulations from BIOME-BGC.
- Develop improved algorithms for estimating LAI and FPAR for different biome types from AVHRR data.
- Test of a generalized ecosystem process model, BIOME-BGC, for the simulation of the carbon, water and nitrogen cycles for different biomes.
- Implementation of the Global Ecological Simulation System (GESSys) to estimate continental net primary production (NPP) and ϵ for the globe.
- Finish formal software engineering of our MODIS products, #14 Leaf Area Index and Fraction Absorbed Photosynthetically Active Radiation, and Daily Photosynthesis - Annual Net Primary Production, #16 and 17.

WORK ACCOMPLISHED:

Our MODIS Team now consists of SWRunning, Team Member, R. Nemani, Associate Team member, and Joe M. Glassy, Software Engineer. The following will be reports on individual activities during this reporting period.

ACTIVITIES OF S.W. Running - Team Member, July 1995 - January 1996,

EOS-IWG
Briefing handout for November 5, 1995 distinguished visit.

SENATOR CONRAD BURNS and
NASA ADMINISTRATOR DAN GOLDIN
AT THE NUMERICAL TERRADYNAMIC SIMULATION GROUP (NTSG)
UNIVERSITY OF MONTANA
NOVEMBER 5, 1995

The Numerical Terradynamic Simulation Group has evolved over the past decade as a lab pioneering new approaches for addressing global to regional ecological problems. The mission of the NTSG group now is to "develop capabilities to quantitatively describe the structure and function of ecosystems, from regional to global scales, using emerging technologies in satellites, geographic information systems, computer simulation and visualization, and biophysical theory." NTSG has executed a number of studies of forest and natural plant communities involving all scales of ecological analysis from 1 acre plots to the entire global terrestrial biosphere. Some projects have been primarily basic research, trying to understand dynamics of the global carbon cycle, or model carbon partitioning in a tree. However, the spinoffs of these basic projects have included building a new forest taxation system for Montana based on theoretical analysis of forest growth potential, evaluating forest recovery after wildfire with satellite data, developing satellite based monitoring capabilities for drought and fire danger, improving range production analysis with satellite and modeling analysis, building microclimate maps to improve snowmelt and river runoff projections.

NTSG research has been funded by the National Aeronautics and Space Administration, National Science Foundation, U.S. Park Service, US Forest Service, National Oceanic and Atmospheric Administration, Dept of Energy, US Fish and Wildlife Service, Montana Dept of Revenue.

The lab currently employs:

- Dr. Steve Running, Director and Professor
- Dr. LLoyd Queen, Associate Professor
- Dr. Kathy Hibbard, PostDoc Res Assoc
- Mr. Saxon Holbrook, Systems Engineer
- Mr. Peter Thornton, PhD Student
- Mr. Mike White, PhD Student
- Dr. Ramakrishna Nemani, Res Asst Prof
- Dr. John Kimball, PostDoc Res Assoc
- Mr. Joseph Glassy, Software Engineer
- Mr. Joe White, PhD Student
- Ms. Galina Churkina, PhD Student
- Mrs. Debra Kendall, Office Manager

ched are samples of our ecological research, beginning with global scale mapping of ieric properties and ending with some prototype regional resource management products. This work is part of NASA Mission to Planet Earth science; as members of the MODIS (Moderate Resolution Imaging Spectroradiometer) Science Team, we plan similar multiple scale ecological analyses with MODIS and other Earth Observing System data, beginning with the scheduled first launch of EOS AM-1 in June 1998.

Global Land Cover: Multi-spectral satellite data at 8x8km was used to produce these consistent and reliable estimates of global land cover. These data will be used in EOS investigations predicting global climate, ecosystem production and water resources.

Land cover change: Changes in global land cover as a result of anthropogenic processes (agriculture, deforestation), estimated using satellite data. Largest changes in land cover (India, China and Europe) are associated with high population densities. Accurate, regular measure of landcover change is an important objective of EOS science.

Vegetation Phenology: Interannual variability in phenology represented by the date of spring leaf growth. The timing of spring leaf growth provides one of the most sensitive measures of biospheric response to climatic fluctuation, and will be mapped by EOS.

Ecosystem Productivity: Annual net primary production estimated at various spatial resolutions by combining remote sensing and GIS technologies with ecosystem simulation models. This shows the relevance of EOS data to regional and local natural resource applications.

Microclimate: Spatial variation in microclimatic conditions mapped from surface weather station data, shown at multiple resolutions. This shows how global climate simulations and forecasts can be translated for regional uses.

Montana Taxation maps: An example of where satellite data and computer models were used in an innovative way to solve a natural resource management problem.

Drought Monitoring: Satellite mapping of the intensity and spatial distribution of drought conditions over the U.S. during the summers of 1988 and 1989. The drought index is derived from greenness and surface temperature observations from NOAA satellites. The extent and severity of the 1988 drought is clearly seen in the August, 1988 image.

Fire danger maps: Changes in Fire Danger Index between June and August of 1988 (the year of the major Yellowstone National Park wildfires) over the northern Rocky Mountains. The FDI reflects surface moisture status estimated from satellite data.

EOS-NSF/LTER: A joint proposal to NASA and the National Science Foundation was selected for start-up funding. An organizing workshop on this project will be held May 1-3, 1996 at the HJAndrews LTER in Oregon.

NSF - National Center for Ecological Analysis and Synthesis: SWR was selected for the Scientific Advisory Board of the newly NSF funded NCEAS. This center can play a significant role in organizing terrestrial research data for EOS science as research priorities are established in the coming year.

Global Climate and Terrestrial Observing Systems (GCOS/GTOS): SWR has been appointed to the Terrestrial Observation Panel for Climate, TOPC, planning a joint Global Climate and Global Terrestrial Observing System (GCOS-GTOS) Terrestrial Observing System.

VEMAP - Vegetation ecosystem modeling and analysis project: VEMAP is a project to intercompare leading biogeography and biogeochemistry models in the US for global change and EOS research programs. The BIOME-BGC model that is part of our MODIS algorithm development for our NPP product is one of the three biogeochemistry models being tested. The other two models are from the Moore and Schimel EOS/IDS teams. The first VEMAP paper has been published in the December 1995 issue of Global Biogeochemical Cycles.

IGBP Biospheric Aspects of the Hydrologic Cycle (BAHC): SWR is working with Drs Dennis Baldocchi and Ricardo Valentini concerned with organizing a global network of CO2 and H20 flux towers for continuous validation of MODLAND vegetation products. This network called FLUXNET, is based on the La Thuile, Italy workshop, and will be published in an issue of Global Change Biology.

Carbon-America: A new activity is being organized to design an atmospheric measurement system for the continental US as a validation source for Earth Systems Models and EOS measurements. This activity is being discussed on the Internet, being called Carbon-America, and is led by Dr. Pieter Tans from NOAA in Boulder, CO.

PIK NPP Workshop: SWR attended the 2nd workshop on global NPP model intercomparisons at the Potsdam Institute for Climate change in Potsdam, Germany. This activity is the most organized effort in the world to determine best NPP analysis for validating the MODLAND NPP product. Steve Prince is leading an activity to build a global database of published NPP measurements. Galina Churkina is writing a paper analyzing the water balance control logic of the PIK models.

GAP Analysis Project: The GAP analysis project is a US National Biological Service funded project to map wildlife habitat in each state using high resolution satellite imagery. I have contacted the national GAP office about sharing their database with the MODLAND team to use as a validation source for our Landcover algorithm. Details of this agreement are being developed.

MEETINGS ATTENDED:

Ecological Society of America annual Meeting, August 1995
Host, MODLAND Landcover meeting, September 1995
EOS-SEC Meeting, September, 1995
NASA BOREAS Meeting, October 1995
MODIS Science Team Meeting, October 1995
EOS Payload Panel Meeting, November 1995

PUBLICATIONS:

VEMAP Members. (1995). Vegetation/ecosystem modeling and analysis project:

comparing biogeography and biogeochemistry models in a continental scale study of terrestrial ecosystem responses to climate change and CO2 doubling. *Global Biogeochemical Cycles* **9**:403-437.

Baldocchi, D., R. Valentini, S. Running, W. Oechel, and R. Dahlman. (1996). Strategies for measuring and modeling CO2 and water vapor fluxes over terrestrial ecosystems. *Global Change Biology* (in press).

Nielson, R. P. and S.W. Running. (1996). Global dynamic vegetation modeling: coupling biogeochemistry and biogeography models. *Global Biogeochemical Cycles* (in press)

Kremer, R. G., E. R. Hunt, Jr., S. W. Running, and J. C. Coughlan. (1996). Simulating vegetational and hydrologic responses to natural climatic variation and GCM-predicted climatic change in a semi-arid ecosystem in Washington, U.S.A. *Journal of Arid Environments* (in press).

ACTIVITIES OF R.R. Nemani - Associate Team Member, July 1995 - January 1996,

OBJECTIVES:

1. Develop a land cover classification scheme compatible with radiative transfer theory.
2. Map RT based global land cover classes using AVHRR Pathfinder data.
3. Develop back-up algorithm to the LUT approach for estimating LAI and FPAR.
4. Develop ancillary databases for the main algorithm based on the LUT.

WORK ACCOMPLISHED:

Land cover classification: Many of the current global land cover classification schemes are designed to accommodate the needs of ecologists, resource managers or global climate and carbon modelers. We propose a land cover classification that is compatible with radiative transfer in vegetation canopies, and useful for deriving biophysical parameters such as LAI and FPAR from remote sensing data. An extensive sensitivity analysis of a 3D radiative transfer model to various input parameters showed only six types of land cover are required for remote sensing applications (Table 1). These are shrubs, grass/cereal crops, broadleaf crops, savana, leaf forests and needle forests. A prototype algorithm is designed to derive the above six classes from AVHRR/Pathfinder data (Figure 1).

Leaf Area Index/FPAR (Backup algorithm): Using the RT model, we did a sensitivity analysis of the relation between NDVI and LAI, FPAR (Figure 2). This sensitivity analysis was performed for each of the 6 biomes and for various background, geometry parameters. Finally, regression equations were fit to the results of the sensitivity analysis (Figure 3). Using the regression equations and AVHRR/Pathfinder data, we generated global fields of LAI and FPAR for 1989 (Figures 4 and 5). Currently, we are in the process of generating monthly fields of LAI and FPAR for all the Pathfinder data from 1982-1993. Utility of the global LAI/FPAR datasets in global carbon and climate models will be explored.

Leaf Area Index/FPAR (LUT algorithm): In order to find out the necessary number of LUT entries that would give accurate retrievals of LAI/FPAR, we are working on the number of necessary discretizations in each of the forcing variables. From extensive literature surveys and AVHRR/Pathfinder data, we are attempting to constrain the number of LUT simulations by constructing accurate ancillary data bases.

Soil background: Our sensitivity analysis showed that soil background has the most significant effect on the relation between NDVI and LAI/FPAR. The analysis also indicated that classifying soil properties into 3 classes (dark, medium and bright) would significantly reduce the variability in the NDVI-LAI relations. Using the Pathfinder data, we identified possible soil conditions by choosing the lowest NDVI throughout out the year. At this time, we extracted the reflectances in red and NIR. Using the red reflectance, we classified the soils into dark, medium and bright (Figure 6), based on spectral observations at the ground level for the three soil types. A global soil line is fit to the lower envelope of the RED-NIR scatter plot (Figure 7). This line indicated that a global soil line exists for all the biomes except barren and shrub lands. For barren and shrub areas, a different soil line is observed.

Leaf Optical Properties: We collected a number of ground based leaf spectra of various biomes from ground based studies. We used the spectra to identify the variability in reflectance and transmittance properties at AVHRR wavelengths. Significant differences in LOP were found between broadleaf canopies and others. Similar analysis will be done for MODIS wavelengths.

Phenology: Identification of green and non-green state of vegetation is an important variable for the retrieval of LAI/FPAR. Two approaches are being tested for this. a) using a minimum NDVI to define green/non-green state, b) use a soil NDVI defined by the red and predicted NIR from soil background analysis (Figure 7).

MEETINGS ATTENDED:

MODLAND meeting on algorithm status, July 1995, Boston
Global land cover algorithms from satellite data, Polson, Montana, Sept 6-9.
MODIS Science meeting, GSFC, November 1995.

PUBLICATIONS:

Nemani, R.R. and S.W. Running. (1996). Global vegetation cover changes and their impact on climate. *Climatic Change* (in press).

Nemani, R.R. and S.W. Running. (1996). Land cover characterization from multi-temporal red, NIR and TIR AVHRR data. *Ecological Applications* (in press).

Nemani, R.R. and S.W. Running. (1996). Implementation of a hierarchical global vegetation classification in biospheric models. *Journal Vegetation Science* (in press).

Myneni, R., R. Nemani, and S.W. Running. (1996) . Algorithm for the estimation of global land cover, LAI and FPAR based on radiative transfer models. *IEEE Trans. Geoscience and Remote Sensing* (in review).

Nemani, R.R., S.W. Running, R. Pielke, and T. Chase. (1996). Global vegetation cover changes from coarse resolution satellite data. *Journal Geophysical Research* (in press).

Hunt, E.R., Jr., S.C. Piper, R. Nemani, C.D. Keeling, R.D. Otto and S.W. Running. (1996) . Global net carbon exchange and Intra-annual atmospheric CO2 concentrations predicted by an ecosystem model and Three-dimensional atmospheric transport model. *Biogeochemical Cycles* (in review).

CAPTIONS:

Table 1: Structural characteristics of vegetation canopies used to define land cover classes.
Figure 1. Land cover classes derived from AVHRR/Pathfinder data.
Figure 4. Seasonal maximum Leaf Area Index for 1989 derived from regression equations of NDVI-LAI and a global land cover map using AVHRR Pathfinder data.
Figure 5. Monthly fields of FPAR (January and July 1989) derived from AVHRR/Pathfinder data at 8 km resolution.
Figure 6. Soil reflectance characterization using red reflectance at lowest NDVI during 1989 from the Pathfinder data.
Figure 7. Relation between RED-NIR reflectances at the lowest NDVI during 1989. A global soil line is apparent for all the biomes except shrubs and barren areas.

ACTIVITIES OF J. Glassy - Software Engineer, July 1995 - January 1996,

OBJECTIVES:

1. Augment our SCF collection of interim algorithm test data by ordering the full set of AVHRR Pathfinder 8-km 10-day composite reflectance data, a trial set of DAO/NMC global daily surface climatology (5) fields (12 daily samples, one per month for 1989) packaged as HDF v. 3.3x volumes, and new samples of MOD09 Surface Reflectance data from the GSFC SDST.
2. Incorporate latest design changes into the MOD15 (FPAR, LAI) algorithm, including provision for a back-up algorithm suite developed by Dr. Rama Nemani, and continue with MODIS University of Montana API software development and documentation.
3. Develop a new generation of our MODIS Science Compute Facility plan, specifically incorporating plans for a) major network services upgrade in 1996, b) addition of large fixed disk store via RAID 0/3 diskpacks in 1996, and c) evaluation and selection of a high performance compute server architecture for the MODIS Compute Ring (MCR) located at the University of Montana SCF.
4. Evaluate candidates for an assistant MODIS software programmer, and select one for hire in January 1996.
5. Continue to participate on current working committees: MODLAND representative on the SDST Advisory Panel (SAP), and NASA EOS Reform Task Force (RTF) with Dr. Steve Running.

WORK ACCOMPLISHED

Science Data Set Development: A number of additional data set elements were ordered during this period, to augment our long term archive for algorithm development and test. Data sets ordered and received this period include a full set of NASA AVHRR Pathfinder 10-day composite reflectance data for the 12 year period 1981 to 1993 inclusive. At 36 granules/year (approx. 36-40MB each granule as compressed, 226MB un-compressed), this archive now totals approximately 17.2Gbytes compressed, or 97.6G bytes un-compressed. Other data sets obtained and staged on disk this period include an annual sample of the new DAO/NMC global daily surface climatology at a 3 hour time step(3 fields: temperature, humidity, solar radiation) comprised of 15th of each month for the year 1989, and a structural sample of the MODIS MOD09_500m surface reflectance data set in HDF format.

MODIS Software Development Tasks:

MOD15: FPAR, LAI Algorithm: Major evolution of the MOD15 (FPAR, LAI) software algorithm dominated the software development task area for this period. A more robust empirically based algorithm suite was added to our primary radiative-transfer model lookup table approach, and software to implement these additions was prototyped on site using NASA global AVHRR Pathfinder data sets. Additional orders for AVHRR Pathfinder data from the GSFC DAAC were placed to implement a wider test period for 8 KM global test of our internally developed end-to-end MODIS Land algorithm suite.

MODIS--Univ. of Montana API Software: Additional MUM API software elements added during this period include statistical and spatial analysis "service pack" extensions to the base MUM API. These were required for development of several key support utility applications, to produce categorical statistical summaries of arbitrarily large images (image_classs and image_freq) and run list-wise search/replace operations on analysis images. Additional documentation products the MODIS University of Montana (MUM) application programming interface (API) were developed during this period. This included diagrams of the MUM data model, and MUM API architecture overview (see attached).

Science Support Utilities: A number of stand alone science support utilities were developed during this period, and an additional set remain in development. All utilities are built as MUM client applications, using the same MUM API that our production algorithms are developed from. In addition to their primary purpose, they are also used as a prototype test bed for new areas of MUM functionality, and to verify API portability across hardware architectures. All utilities are developed to run equally well on multiple hardware/software platforms (AIX, SGI, Win95, and Microsoft NT). Those completed are summarized below:

img_cls	A script driven utility for generating univariate statistical summaries of arbitrarily large analysis images, partitioned by mask image categories.
img_freq	A command line utility for generating frequency distributions of pixel values of an analysis image as partitioned by mask image categories.
mum_recod	A script driven utility to perform list-wise pixel search/replace operations on images of all common data types.
gen_mask	A script driven utility to produce synthetic test images composed of user specified finite set random variates.
guidesyn	A script driver utility to produce synthetic test images composed of

	"guided" gaussian-distributed random variates.
LUT utilities	A set of FPAR, LAI lookup table maintenance and analysis utility programs (lut_extr, lut_freq, lut_find), for selected record subset extraction, generation of frequency distributions of LUT fields from combinatorial inputs, and range wise selection of LUT records for statistical analysis.
geo2rast	A utility for converting coarse scale, geographically projected analysis data images to the Goodes homolosine rectangular plane map projection.

Utilities Currently In Development:

geoscale	A cartographic reclassification utility, for converting NASA AVHRR Pathfinder data layers at either 8KM or 1KM resolution to a user specified geographic projection (angular) resolution.
lamp	A FPAR, LAI LUT analysis and manipulation program, being developed in the xBASE language. It is used to organize and analyze multiple generations of trial FPAR, LAI lookup tables as produced by the Myneni radiative transfer model.

MODIS Science Compute Facility (SCF) Planning/Implementation:

Planning: In response to the need for MODLAND team members to work more closely, a decision was made at the NASA Science Team Meeting to review the compute facilities of the various MODLAND research sites. I have agreed to prepare joint SCF overview plan with SDST lead Ed Masuoka that will assess the relative distribution of compute resources MODLAND wide. Part of this effort will include a new generation SCF plan for the University of Montana, to be reviewed by Ed Masuoka.

Implementation and Future SCF Development: During this period, we took delivery and installed our large scale automated data archive facility, based on a Exabyte Model 440 8mm tape jukebox. This unit is served by a dedicated IBM RS/6000 workstation, and utilizes the Legato software suite to perform scheduled archive services. The University of Montana MODIS SCF Plan has been updated, towards the goal of further developing our dedicated MODIS Compute Ring (MCR) architecture to respond to our increasing responsibility as a MODLAND compute site. The MCR at the University of Montana is evolving in the context of a major network service upgrade to 100Mbps ATM/FDDI circuit on-site for connection to the major DAACS -- GSFC and EDC. The network upgrade is predicated by near term acquisition of a Cisco Catalyst 5000 Model CK5 intelligent switch/router hub controller, slated for 3rd Quarter 1996. This 15 port high performance switch is designed to simultaneously accommodate ATM, FDDI, 100Mbps switched-fast-ethernet circuits, as well as the traditional 10Mbps ethernet, over fiber and twisted pair media. Along with the network service upgrade, which we anticipate will be completed sometime during 3rd and 4th Quarter 1996, the 1996 SCF plan calls for major enhancement of our fixed disk store through the acquisition and deployment of one or more RAID 0/3 diskpack units capable of managing from 32G to 200G of high performance SCSI disk. The RAID 0/3 units will be employed to meet our need to perform global scale algorithm development and test at both the current (8 KM) and 1 KM spatial modeling resolutions.

Lastly: I evaluated the current field of high performance compute servers, for selection of one as the base architecture of our MODIS Compute Ring. Given our current investment in the IBM RISC System/6000 workstation architecture, and the considerable performance potential of the IBM scalable PowerParallel SP/2 workstation series, the SP/2 was selected as the base compute architecture for our MCR. This parallel computer design, scalable to 128 nodes, employs a multiple instruction, multiple-data (MIMD) stream design coupled with a Vulcan style distributed memory (vs. shared memory) layout. The SP/2 runs using a "standard" AIX v.4.1 operating system software, with parallelism handled either by the native application, or under the arbitration of a Parallel Virtual Machine (PVM) style execution environment. We are currently working with IBM representatives (Tom Hinkson, Wes Silloti) on narrowing the specification down further, as well as exploring various medium and longer term acquisition options. As currently envisioned, the MCR will ultimately include one IBM SP/2 compute server (4 to 12 CPU nodes), its slave workstation, several large RAID 0/3 units, the high capacity Exabyte 440 8mm 40 cartridge tape jukebox (280G capacity), as well as the IBM Model 59H file server and other workstations (Model 370, several Model 41T's) we currently operate. All the higher performance MCR workstations will be interconnected via a tight FDDI ring, ATM, and/or via 100Mbps switched fast ethernet circuits.

MODIS Project Staff Development: We have evaluated a small field of applicants for a MODIS Software Programmer and Data Analyst , and have selected one to start January 1996. The additional staff is eventually expected to help us meet the key Level 4 Version 1 software delivery deadlines in June, 1996.

MEETINGS ATTENDED

The NASA Science team meeting in October, 1995 was attended, despite a short term shutdown of the U.S. Government.

A NASA EOS Desktop in the 1990's workshop was attended at Skamnia Lodge in October, 1995.

Algorithm development meetings on-site were hosted, with colleagues from NASA Goddard Space Flight Center (Dr. Ranga Myneni) and University of Arizona (Alfredo Huete), respectively.

Software development meeting with Robert Wolfe of the NASA SDST on site is planned for January 16-17, 1996

A compute server SCF hardware evaluation and planning meeting with Tom Hinkson and Wes Silloti of IBM Corporation is scheduled for January 16, 1996.

ON-GOING ACTIVITIES

The highest priority of on-going activities are the preparation of Level 4 Version 1 versions of contract deliverable algorithms, due June 1996. Other on-going activities include continued participation in the recently formed NASA Reform Task Force (RTF) for EOSDIS review, as well as participation (as MODLAND representative) on the NASA MODIS SDST Advisory Panel (SAP). Despite some funding uncertainties, we're continuing to place increased emphasis on the development of the compute facility (MCR) elements scheduled for 1996: a SP/2 compute server, major increases in RAID disk store, and the network service upgrade.

Land cover classification compatible with radiative transfer theory

	Biome 1 Grass/Cereal crops	Biome 2 Shrublands	Biome 3 Broadleaf crops	Biome 4 Savanna	Biome 5 Leaf forest	Biome 6 Needle forest
Horizontal heterogeneity (ground cover)	No g.c=100%	Yes g.c<40%	minimal g.c~80%	Yes g.c<10%	yes	yes
Vertical heterogeneity (leaf optics, LAD)	No	No	No	yes	yes	yes
Stems/Trunks	No	No	green stems	o/s trees	yes	yes
Under-storey	none	none	none	biome 1	green	green
Foliage dispersion	minimal clumping	none	regular	minimal clumping in u/s	clumping	severe clumping
Needle clumping on shoots	No	No	No	No	No	yes
Crown shadowing	No	No	No	No	yes	yes
Background type	medium	bright	dark	medium	dark	dark

Table 1

Global land cover classes compatible with radiative transfer theory, derived from Red, NIR and thermal-IR AVHRR data

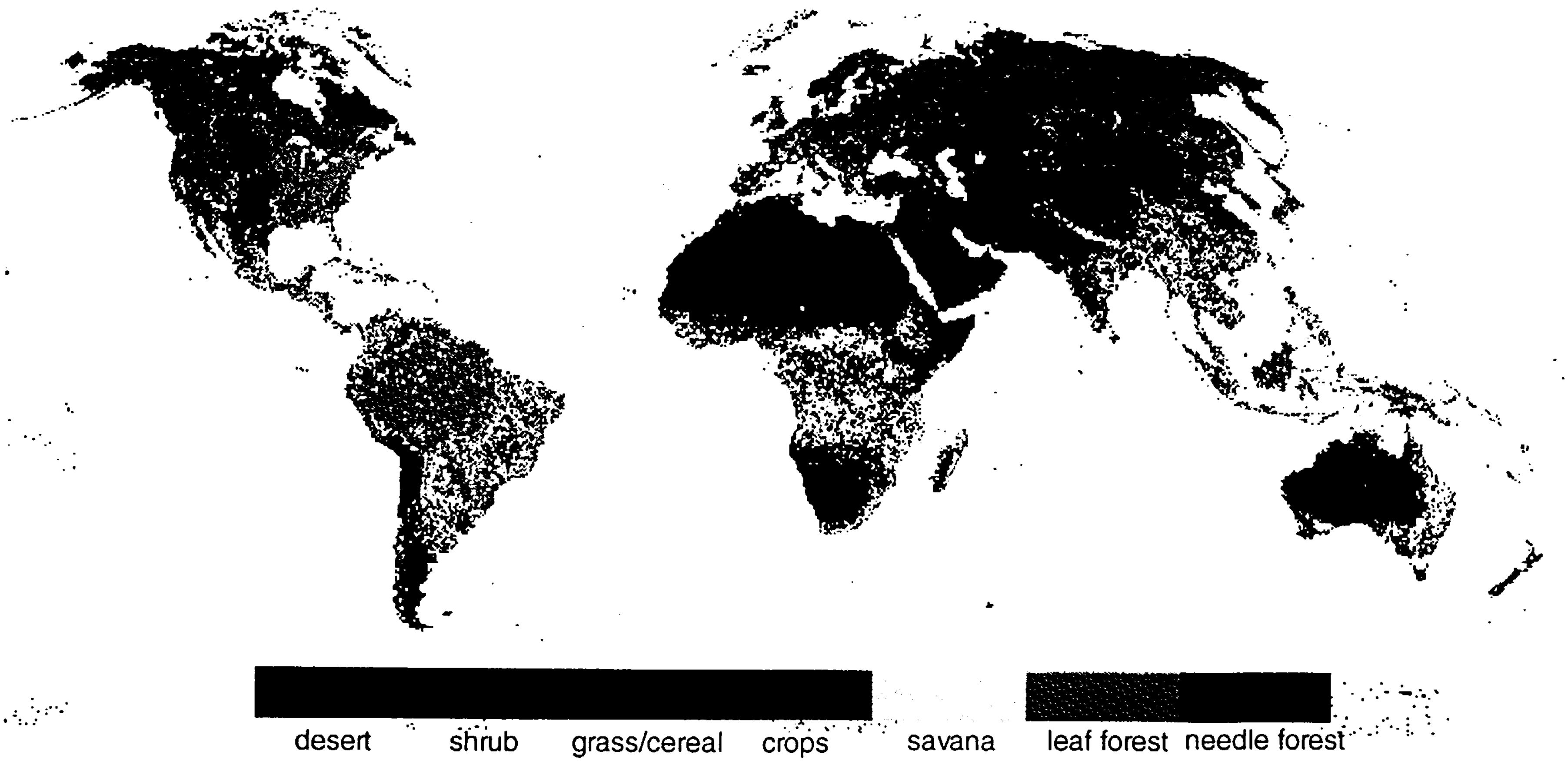


FIG 1

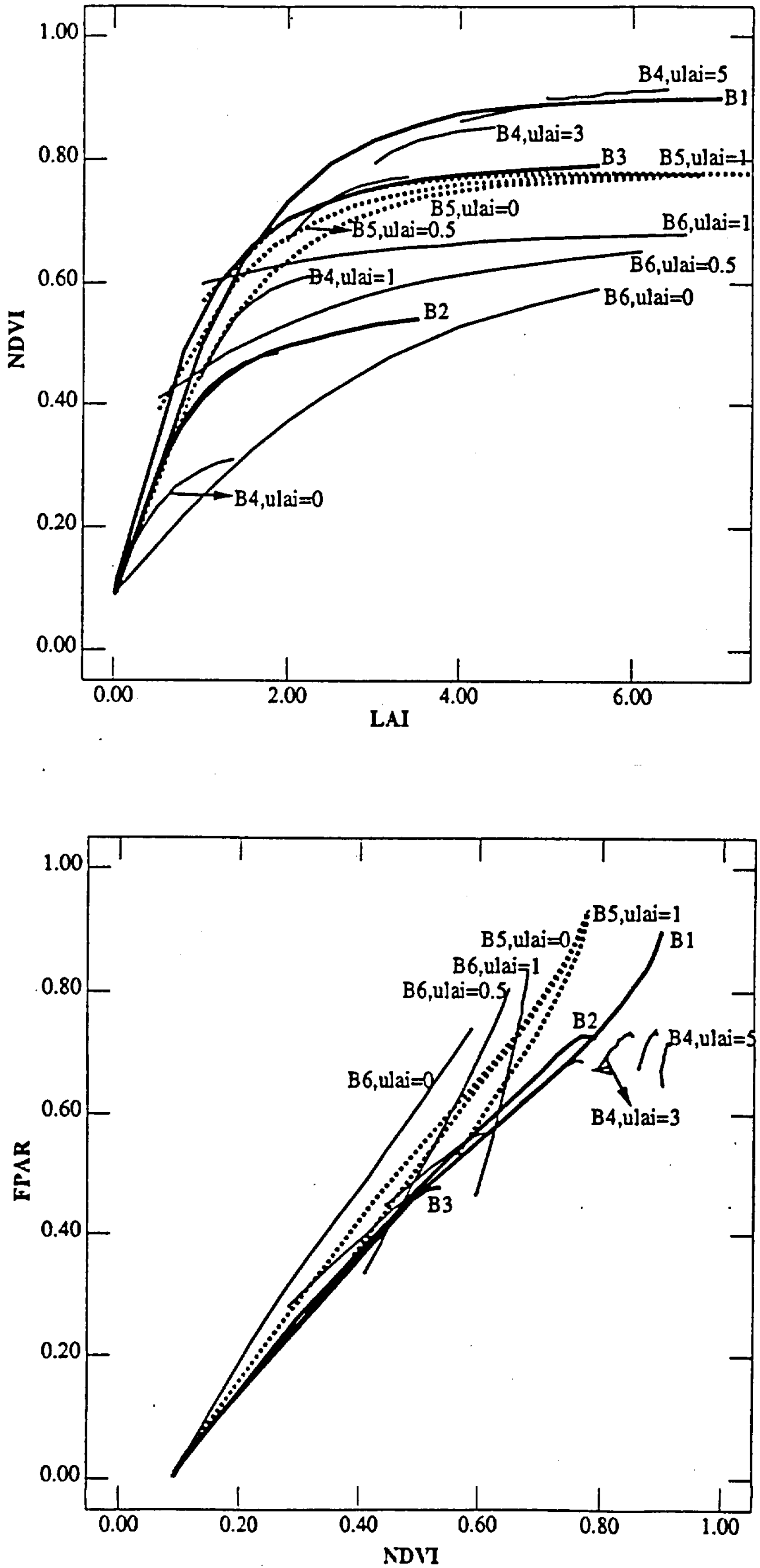


Fig. 2. The relationships between (a) NDVI vs LAI and (b) NDVI vs FPAR in the base case simulation. The notation is as follows: Bn refers to Biomes n, where n = 1 (grasses/cereal crops), n = 2 (shrublands), n = 3 (broadleaf crops), n = 4 (savannas), n = 5 (leaf forests) and n = 6 (needle forests). The abbreviation "ulai" refers to understory leaf area index.

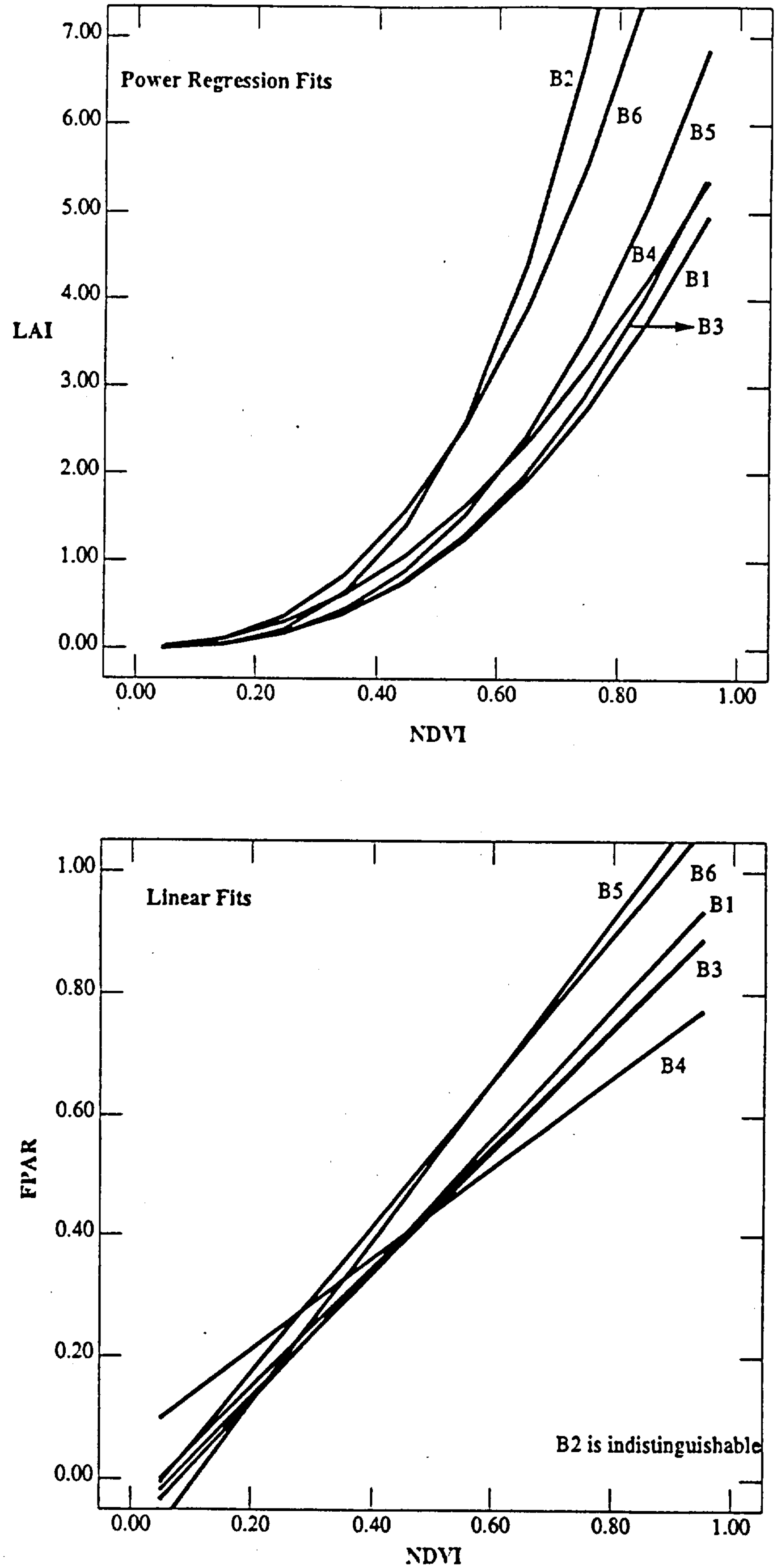


Fig. 3 Regressions fits to all data from the sensitivity analysis. The coefficients of the models are given in Table 3. The notation is as follows: Bn refers to Biomes n, where n = 1 (grasses/cereal crops), n = 2 (shrublands), n = 3 (broadleaf crops), n = 4 (savannas), n = 5 (leaf forests) and n = 6 (needle forests). The abbreviation "ulai" refers to understory leaf area index.

Seasonal Maximum Leaf Area Index during 1989,
derived from NDVI and biome specific LAI-NDVI relations

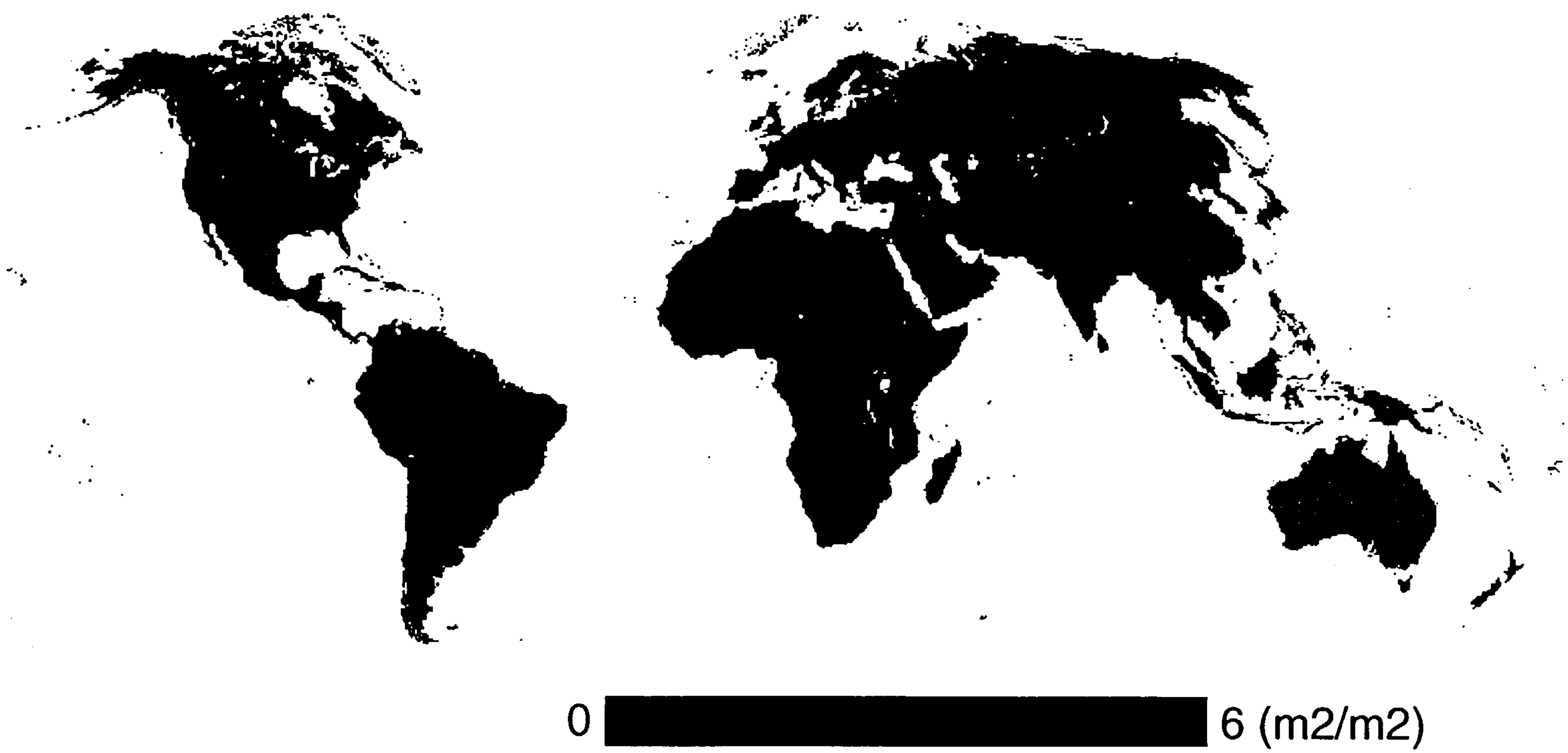


FIG. 4

Fraction of Absorbed Photosynthetically Active Radiation, derived from NDVI and biome specific FAPAR-NDVI relations

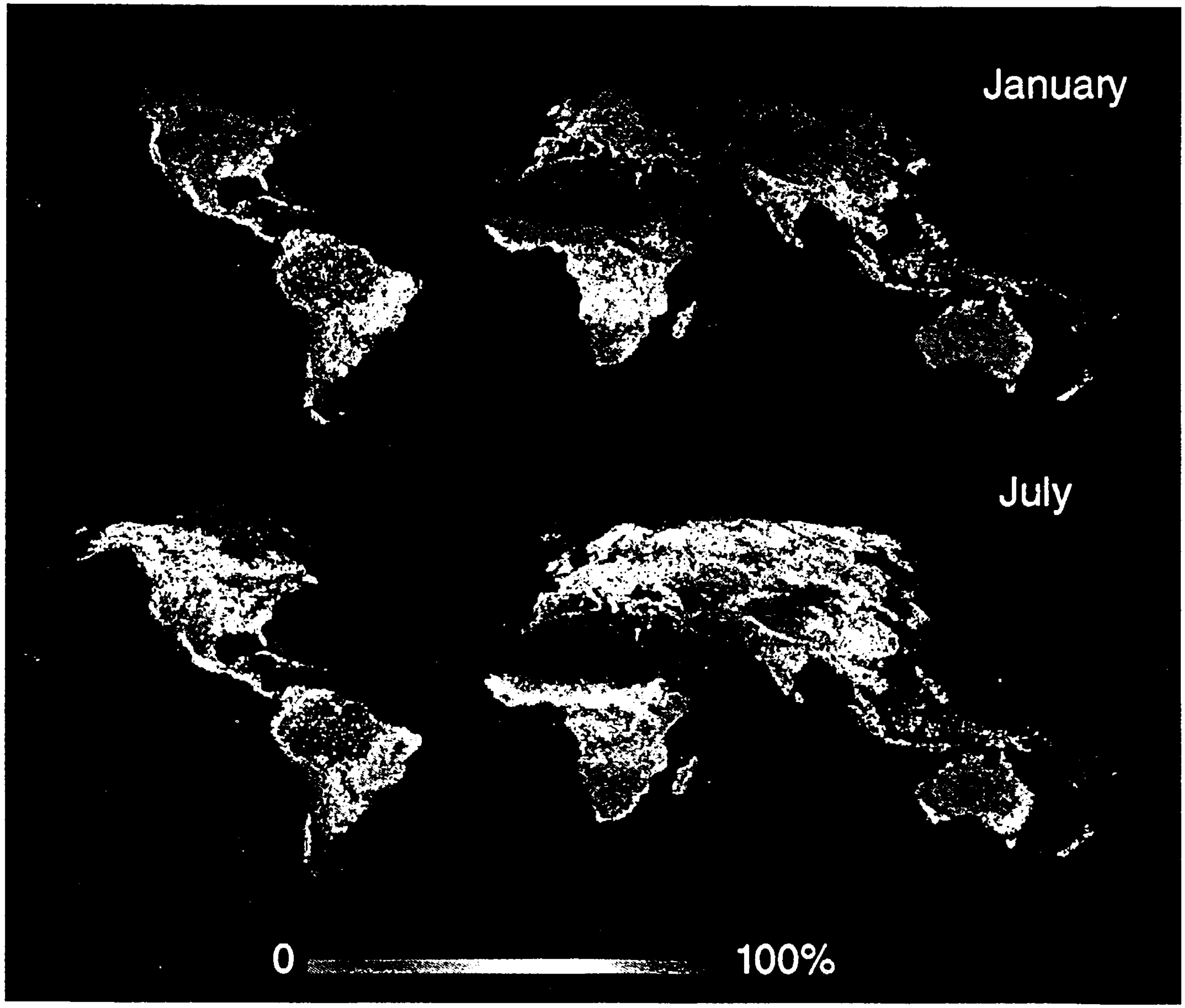


FIG. 5

Soil reflectance characterization from AVHRR/Pathfinder data

Red - dark
Yellow - medium
White - bright

based on red (channel 1) reflectance

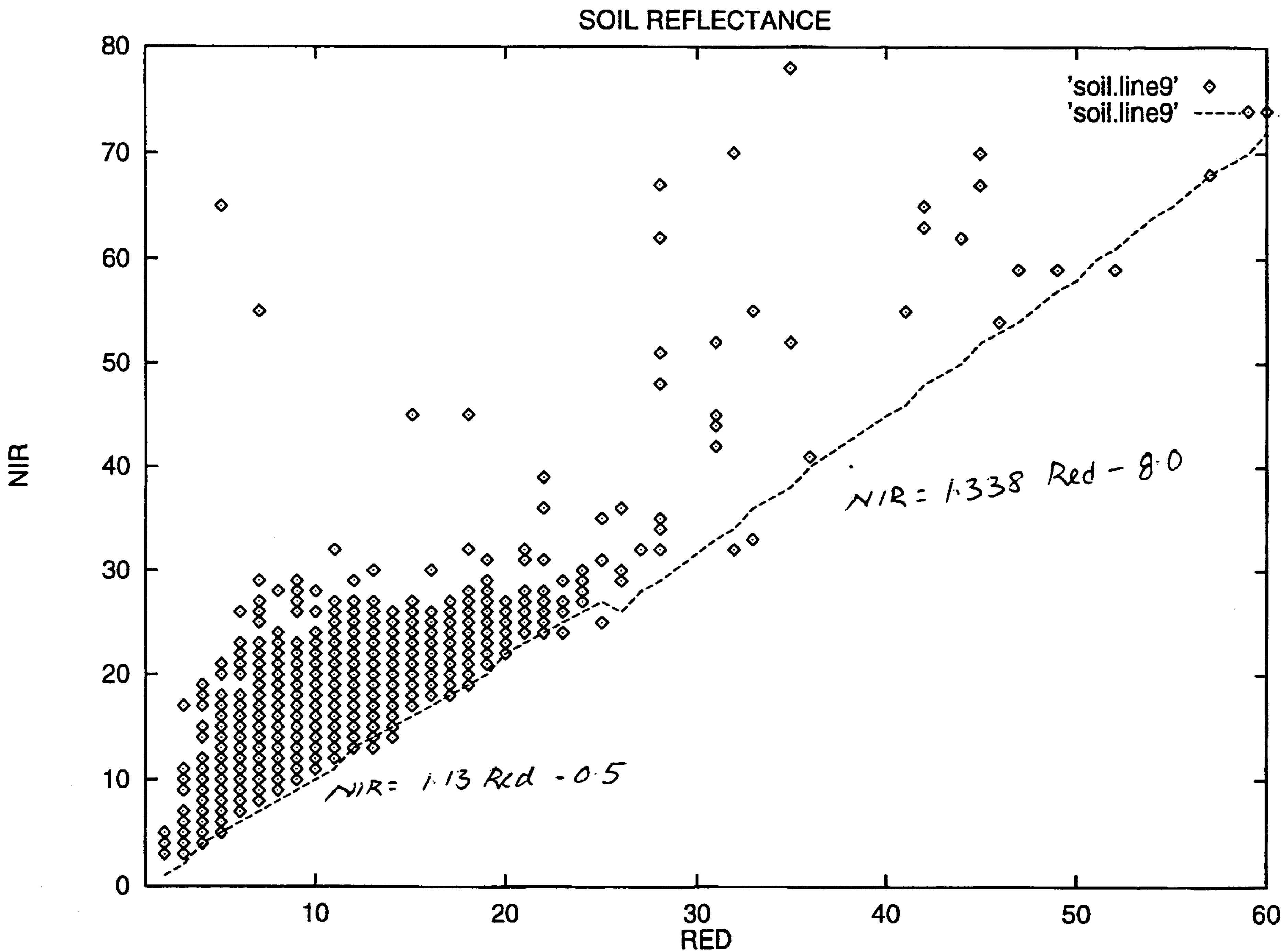
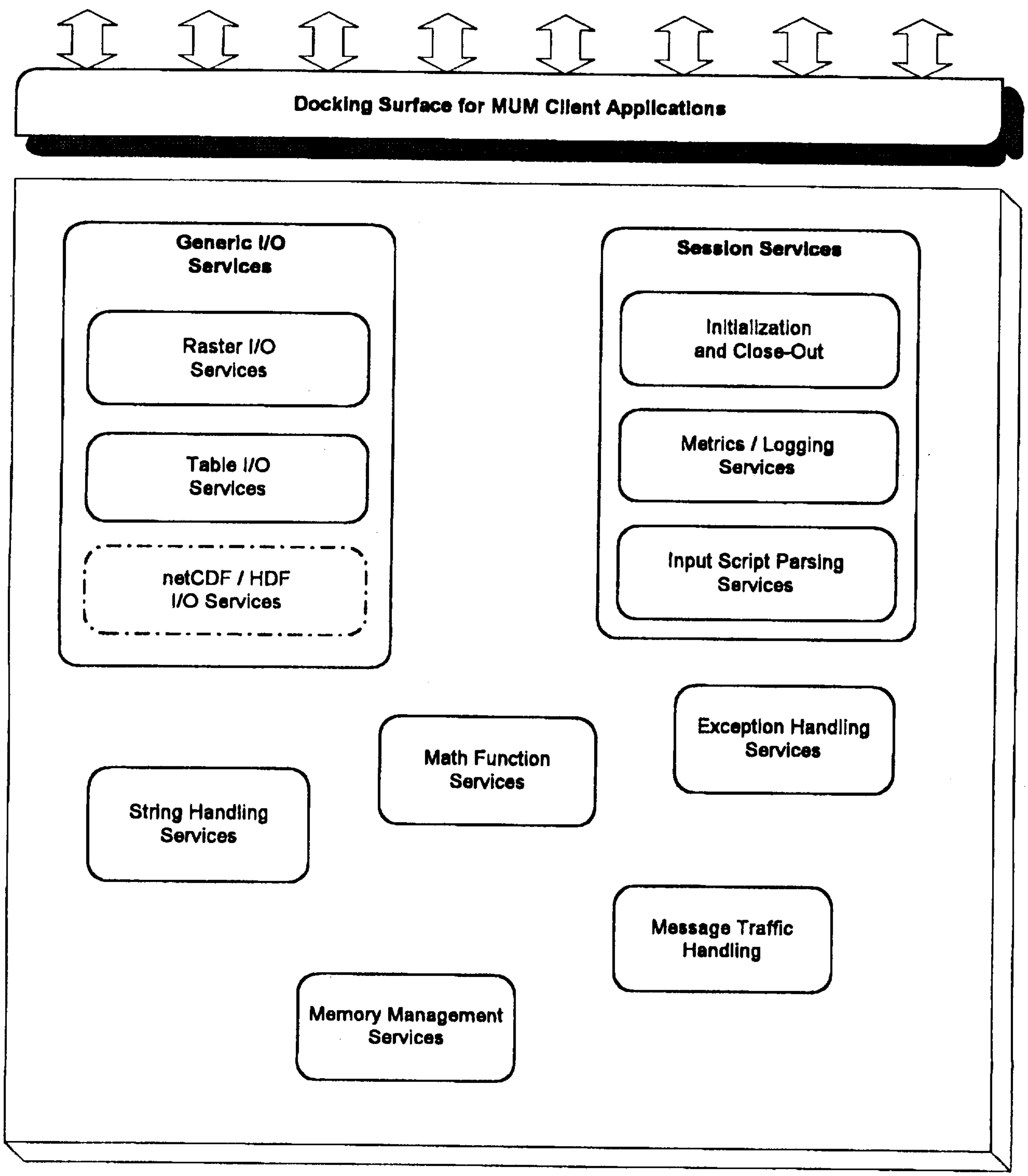

SOIL REFLECTANCE
'soil.line9'
'soil.line9'
NIR
RED
0
10
20
30
40
50
60
70
80
NIR = 1.13 Red - 0.5
NIR = 1.338 Red - 8.0

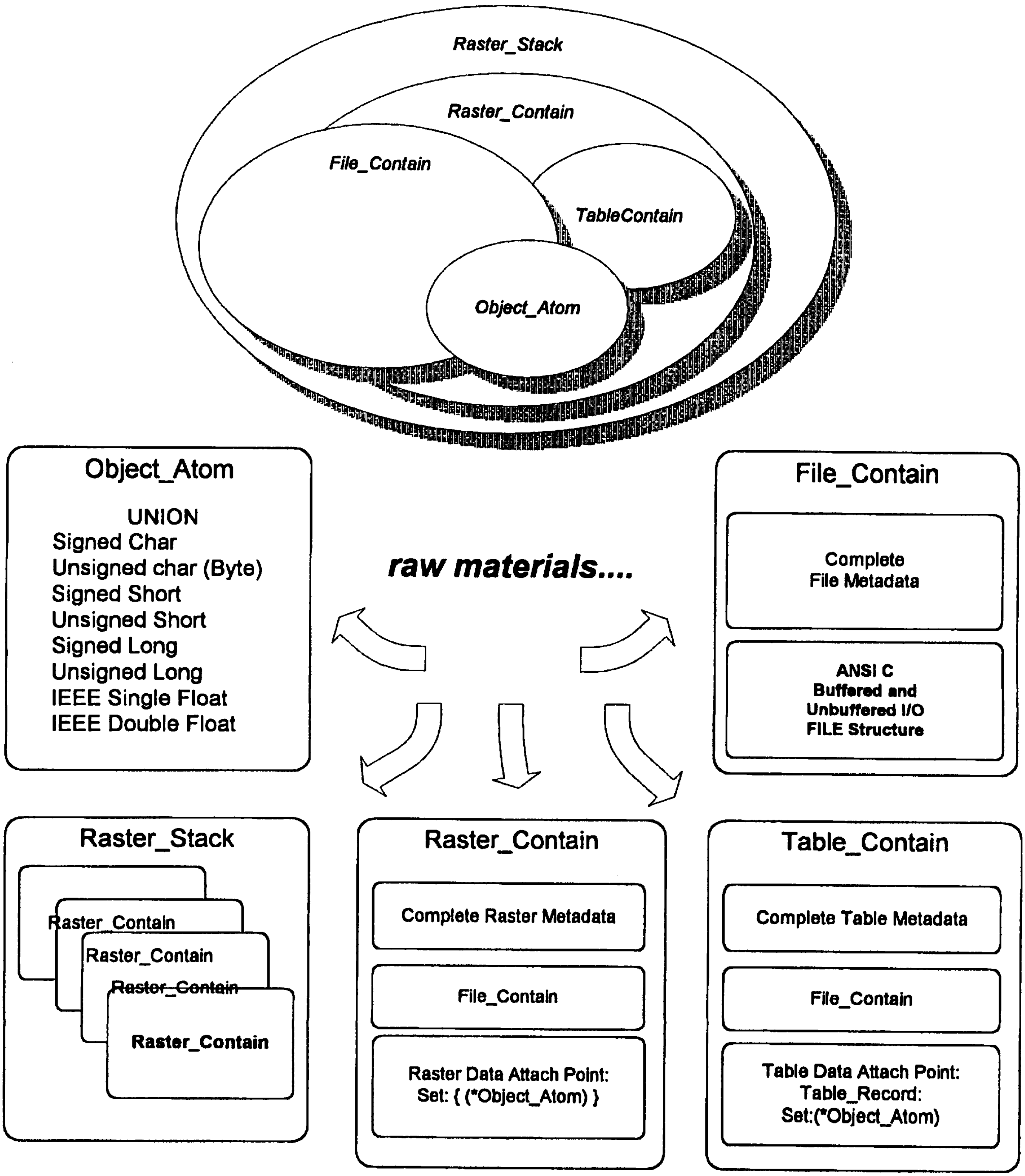
FIG 7

MODIS -- University of Montana (MUM) API Architecture



Joe Glassy, UM SCF
NTSG Lab, 10 Nov 1995

MODIS -- University of Montana (MUM)
API Data Object Model



Joe Glassy, UM SCF